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MEASUREMENT OF CARBON FIBER EXPOSURES TO FAILURE FOR CERTAIN AVIATION COMPONENTS

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The vulnerability to carbon fibers is measured for many components of aviation. These measurements include both the terminal connections of general aviation and the common avionics packages of general aviation. The vulnerability of an air surveillance radar [ASR-3] is also measured.

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TABLE OF CONTENTS

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TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

A. Purpose of the Work

Because of the increased hazard of accidental release of carbon fibers [CF] and their unknown effect on electrical items, a Federal Study Program was organized by the Office of Science and Technology Policy of the Executive Branch of the government [OSTP]. This group tasked certain government agencies and departments with the investigation of the effects of accidently released CF. As part of this tasking, NASA was employed to investigate the hazard of accidentally released CF from a carbon fiber composite used as a structural material for commercial airframes. This investigation was to include a measurement of the amount of single fibers released in a downed aircraft. scenario and the length spectrum of these released fibers, the assesment of the vulnerability of the electronic packages of both commercial and general aviation, and the vulnerability of the electronics in the surrounding area to include civilian equipment and airport aircraft surveillance equipment. Because of past experience in vulnerability measurements, the Ballistic Research Laboratory (BRL) was tasked by NASA to measure the vulnerability of some of this electronic equipment.

This report is concerned with the CF vulnerability of electronics used in commercial and general aviation, and the vulnerability of an ASR-3 air surveillance radar used by ground controllers for handling air traffic. The radar is usually located near airports, where there is a higher than average probability for an accidental CF release.

B. Model Development

The model used to calculate vulnerability of electronic equipment has been developed and fully explained by R. D. Shelton and J. R. Moore in an earlier work.[1] A precis will be presented here.

The two basic concepts used in the model are concentration and exposure; their relationship is defined as

$$E[\vec{r},t] = \int_0^t C[\vec{r},t]\, dt \qquad (1)$$

where E and C are the exposure and concentration respectively at a position vector $\vec{r}$ and a time t. If it is assumed that the failure is caused by a single fiber, the vulnerability equation can be written

$$P_F = 1 - e^{-\frac{E}{\langle E \rangle}} \qquad (2)$$

[1] *R. D. Shelton and J. R. Moore, "A HAVE NAME Vulnerability Model (U)," BRL Report No. 1912, August 1976, SECRET.*

where P_F is the probability of failure and

$$\langle E \rangle = \sum_{i=1}^{n} \frac{E_i}{m} \qquad (3)$$

where n is the total number of tests, E_i is the exposure at the time of failure or at the termination of the ith test and m is the number of failures during that series of tests. In the event that no failures occurred, $\langle E \rangle$ is assumed to be greater than the total exposure of all the tests. This model assumes a failure is caused by a single fiber and is a worst-case prediction for an accidental release scenario where fiber lengths are very short and more than one fiber are required for a failure.

II. EXPERIMENTAL FACILITIES

A. Experimental Chamber

1. S-280 VAN. The S-280 van is equipped with the main test chamber [3.54m x 2.2m x 2m] and an anteroom [2m x 2.2m x 2m] for target preparation and experimental setup. The test chamber is equipped with a large table in the middle where most experimental targets and fiber detection equipment are located. The chamber is also equipped with 10 muffin fans, variac controlled, to keep the fibers in suspension for a long period of time. This system has been used to create an average fiber concentration of 10^3 f/m^3 for as long as 15 minutes, without the addition of fibers. Because experimental data recording equipment must be outside the fiber environment, experimental interwiring is done by means of a sealed cable junction box. Also, a large window in the side of the chamber allows observation of the fiber exposure area. The anteroom is provided with a floor vacuum cleaner and sticky paper foot pad to prevent the contamination of the outside laboratory with fibers. Both areas are also supplied with 110 and 220 volt, 60 hz, 3ϕ, 15 amp electrical circuits.

2. Flow Through Chamber. This chamber is fabricated from sheet metal and has an overall length of 4.25m. The dispensing box outputs through a 0.2m square opening which expands into the test section which is 0.6m x 0.45m and 1.2m in length. After the experimental section, the cross section decreases to 0.45m square. The airflow through the chamber is maintained by four muffin fans which are variac controlled. The airflow is variable from 0.3m/sec to 5m/sec.

3. <u>Small Free Fall Chamber.</u> This chamber is a fiber free fall chamber with a minimum of air current flow. The chamber dimensions are 1.2m x 1.2m x 1.4m. It is completely enclosed and sealed to prevent fiber dispersion into the laboratory. Two of the sides of the chamber are glass for easy observation of the target during exposure.

4. <u>Large Free Fall Chamber.</u> This exposure chamber is a large room (3.5m x 2.5m x 2.1m). The chamber entrance is an anteroom (1.6m x 2.5m x 2.1m) which is used for target preparation and decontamination after exposure and fiber dispenser preparation. Another function of the anteroom is to control the spread of carbon fibers to the laboratory area. The chamber is equipped with 110 Volt, 3ϕ, both 60 hz and 400 hz circuits. Fiber circulation is enhanced in the chamber by having six muffin fans to create a small air circulation. The chamber is also equipped with two viewing windows and a cable/wire system connected to the experimental area for target monitoring and active detector connections.

B. <u>Dispensing System</u>

1. <u>Free Fall System.</u> This fiber dispenser was developed at the BRL and is used in both the S-280 van and the free fall chambers. The cylindrical dispenser is 1m high and 0.15m diameter. The exit at the top is slanted and its cross section constricted to increase the velocity of the dispensed fibers. At the base of the dispenser is a nozzle which emits short bursts of air to lift the fibers aloft. The single fibers are then transported upward through the cylinder at a velocity of about a factor of two greater than fiber fall velocity (2.5 cm/sec). The clumps which are heavier and have a greater fall velocity settle back to the bottom where they are relofted. The output of this dispenser is 95% single fibers with no fiber breakup. Because the fibers are cut before they are placed in the dispenser and no automatic fiber chopper is involved, the fiber length spectrum is 98% the nominal length ± 0.5mm[2].

2. <u>Venturi System.</u> This system consists of a 1 cubic meter container and is used whenever an airflow either across the target or into the target is required. Precut fibers are drawn into the mixing chamber by a high pressure venturi action. The violent action separates the fiber clumps into single fibers which remain suspended in the box. These suspended fibers are then drawn from the box through the target being exposed. For further information about the flow-through chamber and the dispensing system see reference 3.

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[2] *Neil M. Wolfe, Private communication.*

[3] *William I. Brannan, William P. Bucher, Samuel C. Thompson, and John A. Morrissey, "Generic Target Airflow Test Chamber," Ballistic Research Laboratory Technical Report ARBRL-TR-02080, June 1978, UNCLASSIFIED. (AD #B029338L)*

C. Fiber Detection

The active method of fiber detection used in this experiment was the BRL ball gauge method. This particular fiber detection method made use of a charge transfer principle. The output of the BRL ball gauge is fiber length dependent. All pulses corresponding to fibers whose lengths are greater than half the nominal length being dispensed are recorded in a multichannel analyzer in the multichannel scaling mode. The data stored are the instantaneous concentrations, the integration of which is exposure. A typical plot of the data can be seen in Figure 1. All exposure numbers quoted in the report were determined using the BRL ball gauge. For further information about this detector and its calibration, see reference 4.

D. Fiber Type

Most composite material is fabricated using Hercules AS fibers or Thornel T-300 fibers, manufactured by Union Carbide Co. Because of the difficulty experienced while trying to dispense sized T-300, it was decided to use Hercules AS for all the avionics tests. Hercules HMS fibers were used for the tests performed on the ASR-3 radar unit. The fall velocity for all three fiber types is the same, 2.5 cm/sec. The single fiber resistances are 2000 ohm/cm for HMS, 5000 ohm/cm for AS, and 5300 ohm/cm for T-300. Because the resistance of the AS and T-300 fibers is approximately equal, it was felt that there would be no significant difference in the vulnerability data.

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[4] *John A. Morrissey, William I. Brannan, and Samuel C. Thompson, "Calibration BRL Ball and Sticky Cylinder Detector System, "Ballistic Research Laboratory, Technical Report ARBRL-TR-02079, June 1978, UNCLASSIFIED. (AD #B029204L)*

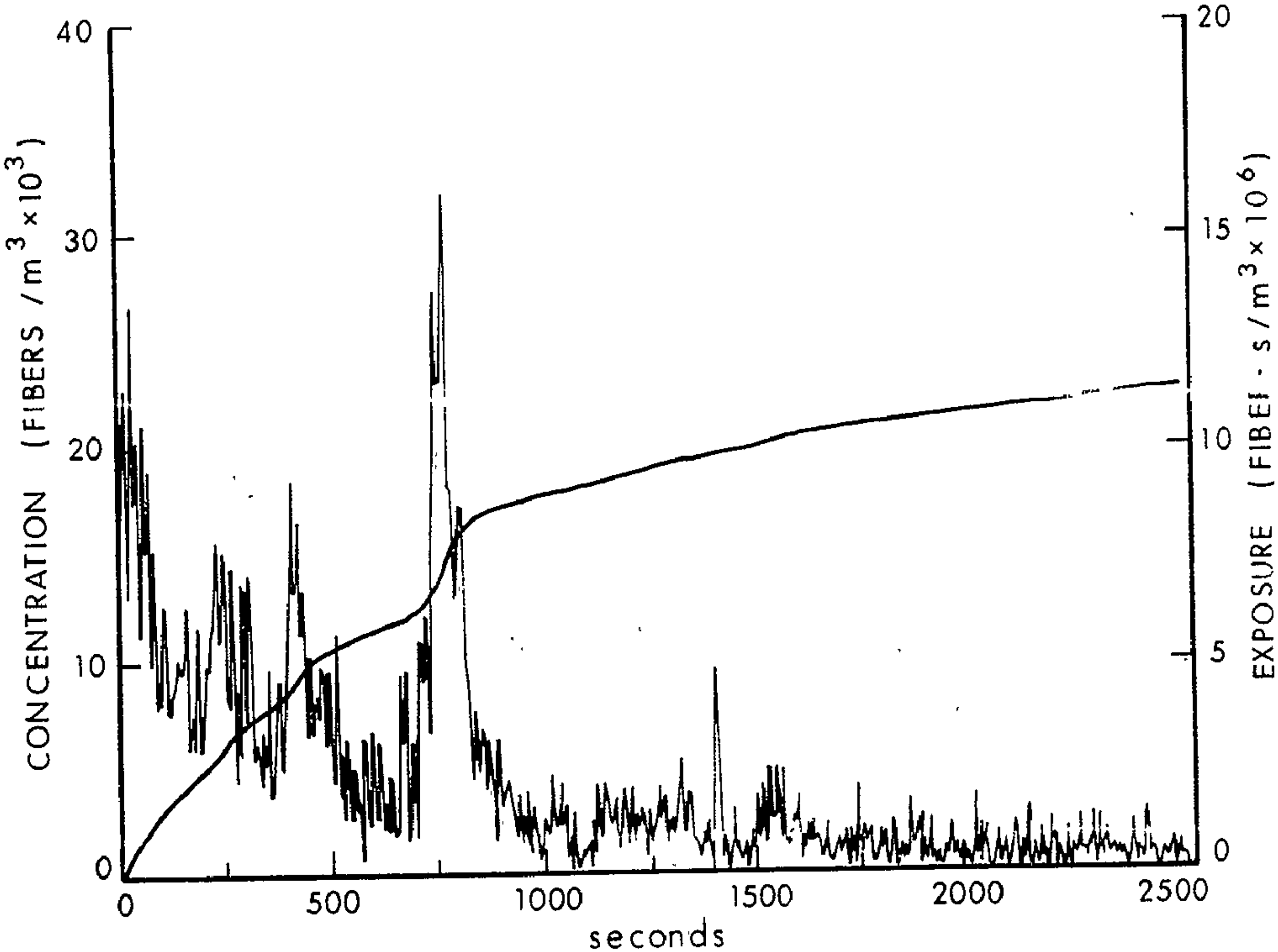

Figure 1. A Typical Concentration and Exposure Plot

III. COMMERCIAL AIR FRAME COMPONENTS

A. Selection Criteria

During an inspection of the airframe of the wide body jets, some areas of potential vulnerability were noted. The first area of concern was the interconnecting wire termination points (Burndey blocks) with their exposed terminals. Another area of concern was the exposed terminals of the control relays. A third concern was the vulnerability of the avionics packages housed in the electronics bay of the aircraft. The avionics components testing was done at NASA Langley Research Center (LaRC). The vulnerability testing of the exposed terminals of the relays and the Burndey blocks was performed at the BRL. The testing in this particular area was meant to measure the probability of a fiber bridging two adjacent terminals, whether it be across an insulating barrier as with the Burndey blocks or between adjacent terminals without insulating barriers as in the case of the relays. It is not within the scope of this work to predict any aircraft vulnerability based on the numbers which are generated.

B. Target Description

1. Burndey Blocks. The Burndey blocks are used mainly in the horizontal position in the airframe and carry two predominant voltages, 28 Vdc and 110 Vac, 400 hz. The objective of this experiment was to measure the probability of a short between adjacent blocks or to the supporting ground bar as a function of exposure. Two identical connector bars were set up with four identical Burndey block elements on each. Figure 2 is a sketch of one connector bar assembly. Three different types of Burndey blocks were used in each element. They were the double width type, YHLZ-8, the single width type, YHLZ-44, and the single width type with a dividing insulator, YHLZ-22. The YHLZ-8 was the center block of the three block element, and it was the block at voltage (28V dc or 110V ac). On each side of the YHLZ-8 was a single width block, the YHLZ-44 and YHLZ-22.

Data were recorded by measuring the voltage drop across a series resistor (9.1Ω when using 28V dc and 100Ω when using 110V ac). In the case of monitoring the 110V ac, a half-wave rectifier system was built to monitor the current flow. Figures 3 and 4 are schematics of the monitoring circuits for 28V dc and 110V ac, respectively.

During the data acquisition and data analysis, each Burndey block element was viewed as a separate target. A failure was interpreted as a measured current between the center block, the terminal with the applied voltage, and the adjacent blocks or the supporting bar. In the data analysis, once a failure occurred with either the block or the supporting bar, that particular occurrence was not counted again.

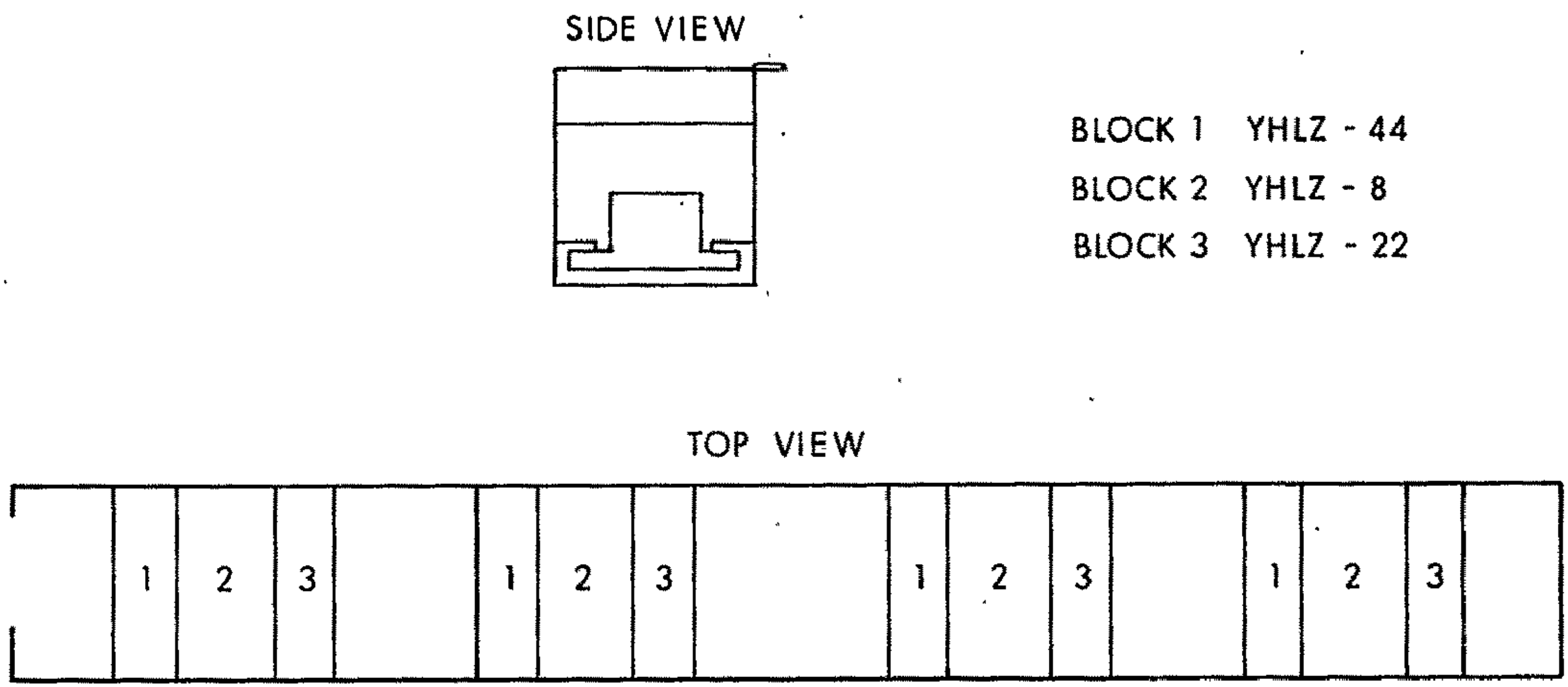

Figure 2. Burndey Block Target Assembly

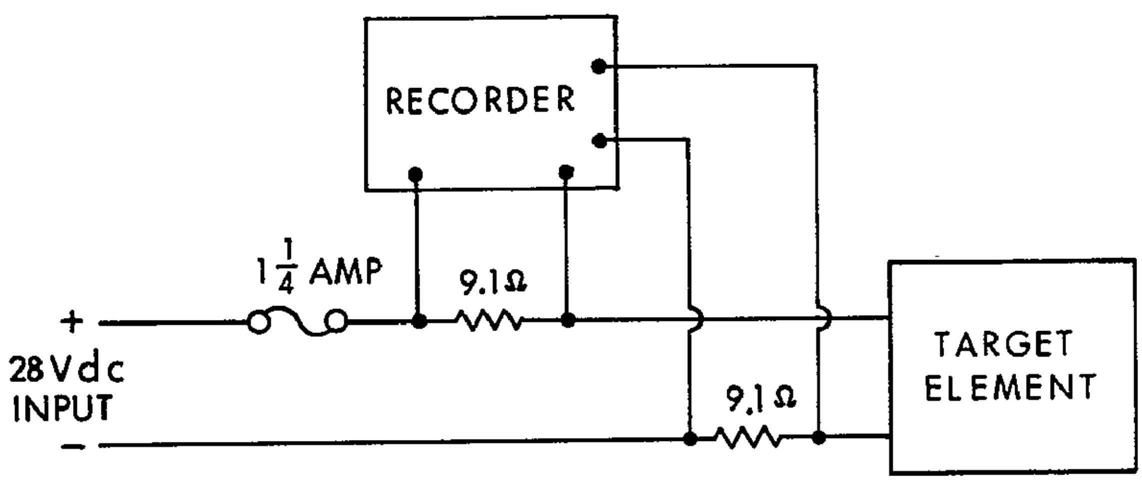

Figure 3. DC Monitoring Circuit

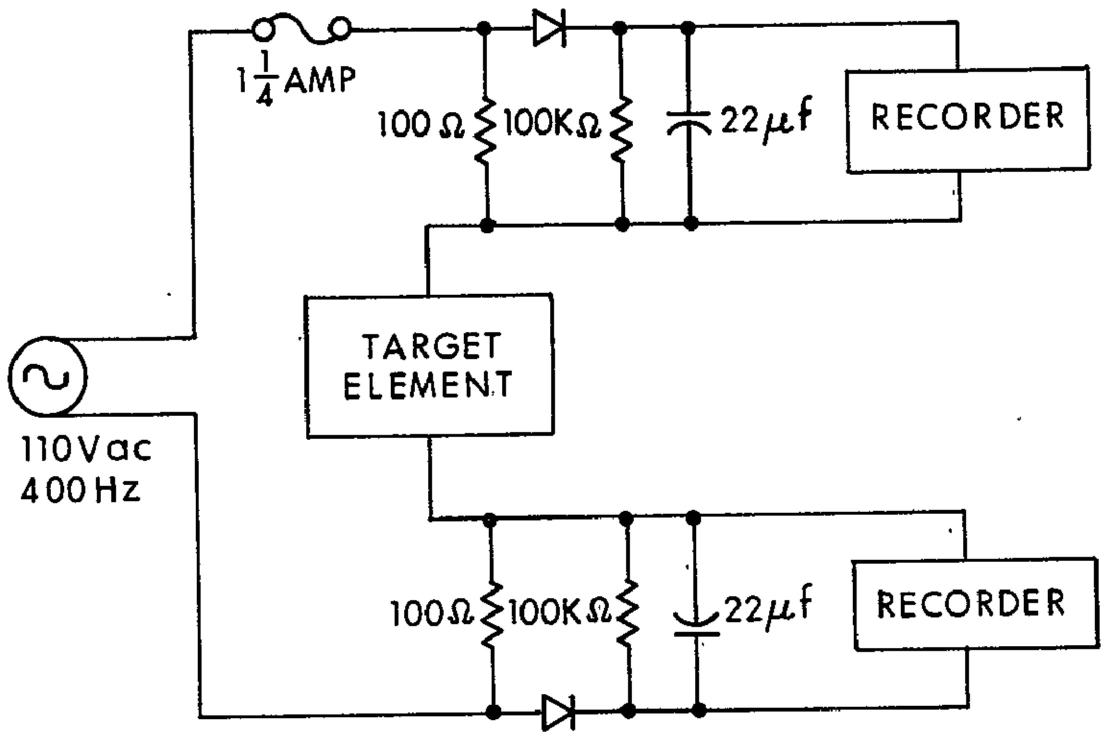

Figure 4. AC Monitoring Circuit

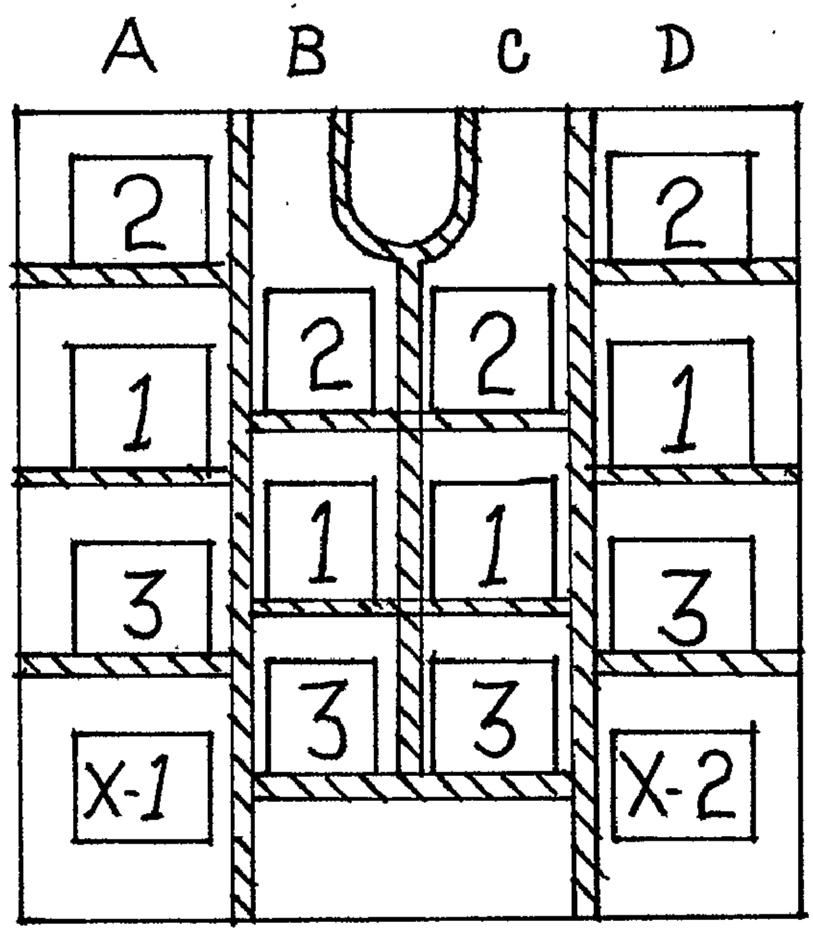

Figure 5. Top View of Relay

2. Air Frame Relay. The relays, as used in the aircraft electrical system, are mounted in both the horizontal and vertical position with both 28V dc and 115V ac, 400 hz, on their terminals. The relays used for the tests were the ones received from aircraft manufacturers and were made by the Leach Corporation. The relay is 4 pole, double throw, with a 28V dc coil. The switching contacts are rated at 10 amps for 28V dc and at 6 amps for 115V ac, 400 Hz. The Leach part number for the relay is 9274-3643.

The objective of these tests was to determine the probability of a short between the adjacent terminals of the relay and between relay contacts across an insulating barrier. The probability of a short as a function of exposure was measured. Two identical relays were mounted on a board 25cm apart. This board could be mounted in either the vertical or horizontal position. Figure 5 shows a top view of a relay and its terminals. In the open position, terminals 2 and 3 in each connector row are common. To determine the average exposure to failure, <E>, for relay was not activated and voltage (28V dc or 115V ac, 400 Hz) was applied to A-2 and D-2. To determine the average exposure to failure for a short across the insulating barrier, the terminals of row B were connected together as were the terminals of row C. The input line, which was common to connectors A2 and 3 and D2 and 3, was monitored on a strip chart recorder along with each return line, A1, D1, X1, X2, row B, and row C. The monitoring circuits are shown in figures 3 and 4 for 28V dc and 110V ac, respectively.

C. Data Acquisition

For both series of tests, a failure was defined as a short, instantaneous or sustained, between the powered (28V dc or 115V ac) terminal and the element connected to the return line. A failure was recorded as a current flow in each of two categories, $I \leq 10$ ma and $I > 10$ ma. The first failure which occurred for each target in each current category established the point used to calculate the exposure to failure. Strip chart recorders connected to the targets were used to record the data. During the complete series of tests, there were no current spikes greater than 100 ma and no evidence of arcing.

The exposure at the time of failure was considered to be the average of two ball gauge readings in the vicinity of the target.

D. Test Procedure

The S-280 van exposure chamber with the free fall fiber dispenser was used for these tests. Each target was mounted on the table in the center of the chamber with the charge transfer detector at each end of the table. The fiber lengths dispensed were 3.5mm, 7.0mm, and 15mm of Hercules AS. Before each trial, both the Brundey block and relay targets were completely vacuumed, brushed, and cleaned with a jet of high pressured air. There were two independent trials for each length, voltage, and orientation. Between fiber length changes, the chamber was completely vacuumed and wiped down with a wet sponge. After the cleaning process, the chamber circulation muffin fans were activated and a sticky paper background sample taken. Each trial was continued until all target failures had occurred or approximately $2 \times 10^7 \frac{f\text{-}s}{m^3}$ total exposure was reached.

E. Data Analysis

1. Burndey Terminals. Since each Burndey element was assumed to be an independent target, there was a total of 16 targets per fiber length tested, two connector bars with 4 elements each for 2 tests at each length. The <E> for each category was generated by summing the exposure to failure for all failures and adding to that the trial exposure multiplied by the number of targets which had no failure. This sum is then divided by the number of failures to provide an <E>. This method of data analysis is called the Maximum Likeihood Estimate and is thoroughly presented in Appendix A. Tables I and II are a summary of all the data and the <E> established by their analysis.

2. Air Frame Relay. Figure 5 shows a top view of the relay. In columns A and D, terminals 2 and 3 were common and at voltage (28V dc or 115V ac). A current spike between the powered terminals (2 and 3) and the other terminals in the same column (1 or X1 for column A and 1 or X2 for column D) was considered a type 1 failure (short to adjacent terminals). Since all non-powered terminals were monitored separately, it was possible to discriminate "hits", thus making terminals A1, D1, X1, and X2 each separate targets. Therefore, there were four type 1 targets per relay, 2 in the A column and 2 in the D column. There were also two type two targets (across insulating barrier) per relay, A2 or 3 to column B and D2 or 3 to column C. Exposure to failure for any target was considered to be the recorded exposure when the first "hit" occurred for that target in any particular current category. Because terminal 1 in both column A and D was adjacent to a voltage terminal on both sides, the observed exposure to failure for a "hit" to terminal A1 or D1 was multiplied by 2 to equate the data to that obtained on the other type 1 failure terminals (X1 or X2), which had a voltage terminal on only one side. The same correction was made to type 2 data because there were two voltage terminals A2 and A3 and the data are meant to reflect the exposure for a failure of single terminals across an insulating barrier. These data are summarized in Tables III and IV. During each trial there were two relays, each having four type 1 and two type 2 short possibilities, and since there were two runs at each length, there were 16 independent targets of type 1 and 8 targets of type 2 for each length. The <E> for each category was generated by summing the exposure to failure for all target failures and adding to that the final exposures multiplied by the non-failures. This sum was then divided by the number of failures.

While a momentary short may cause problems in a digital circuit, a continuous current flow for a long period of time would be required to affect most circuits which would be controlled by a relay system.

TABLE I. 28V BURNDEY BLOCK DATA SUMMARY

Height Code 1 - $I \leq 10$ ma

2 - $I > 10$ ma

Type Code 1 - Failure by Short to adj. Terminal

2 - Failure by Short to supporting bar

V_o - 28Vdc

RUN NOS.	FIBER LENGTH	HEIGHT CODE	TYPE CODE	NO. OF TARGETS	NO. OF FAILURES	<E> f-sec m^{-3}
AV1-AV2	7mm	1	1	16	1	2.8×10^8
		1	2	16	1	2.9×10^8
		2	1	16	0	$\geq 2.9 \times 10^8$
		2	2	16	0	$\geq 2.9 \times 10^8$
AV3-AV4	3.5mm	1	1	16	1	2.9×10^8
		1	2	16	0	$\geq 3.1 \times 10^8$
		2	1	16	0	$\geq 3.1 \times 10^8$
		2	2	16	0	$\geq 3.1 \times 10^8$
AV5-AV6	15mm	1	1	16	3	0.7×10^8
		1	2	16	1	3.1×10^8
		2	1	16	0	$\geq 3.1 \times 10^8$
		2	2	16	0	$\geq 3.1 \times 10^8$

TABLE II. 115V BURNDEY BLOCK DATA SUMMARY

Height Code 1 - I $\leq$ 10 ma

2 - I > 10 ma

Type Code 1 - Failure by Short to adj. Terminal

2 - Failure by Short to supporting bar

V_o - 115Vac. 400Hz

RUN NOS.	FIBER LENGTH	HEIGHT CODE	TYPE CODE	NO. OF TARGETS	NO. OF FAILURES	<E> f-sec m^{-3}
AV7-AV8	7mm	1	1	16	9	0.23×10^8
		1	2	16	2	1.3×10^8
		2	1	16	1	2.6×10^8
		2	2	16	0	$\geq 2.6 \times 10^8$
AV9-AV10	15mm	1	1	16	5	0.32×10^8
		1	2	16	10	0.16×10^8
		2	1	16	3	0.64×10^8
		2	2	16	5	0.36×10^8
AV11-AV12	3.5mm	1	1	16	3	1.0×10^8
		1	2	16	0	$\geq 3.0 \times 10^8$
		2	1	16	0	$\geq 3.0 \times 10^8$
		2	2	16	0	$\geq 3.0 \times 10^8$

TABLE III. DATA SUMMARY - 28 Vdc
AIRFRAME RELAY

HEIGHT CODE

1. I $\leq$ 10 ma

2. I > 10 ma

TYPE CODE

1. Short to Adjacent Terminal

2. Short Across Insulating Barrier

V_o - 28 Vdc

RUN NUMBER	FIBER LENGTH	HEIGHT CODE	TYPE CODE	#TARGETS	#FAILURES	<E> f sec/m³
AV-13 AV-15	7	1	1	16	8	0.3×10^8
Horizontal		1	2	8	4	1.32×10^8
		2	1	16	4	0.8×10^8
		2	2	8	0	$\geq 2.80 \times 10^8$
AV-14 AV-16	7	1	1	16	2	1.85×10^8
Vertical		1	2	8	2	1.62×10^8
		2	1	16	0	$\geq 7.20 \times 10^8$
		2	2	8	0	$\geq 3.60 \times 10^8$
AV-17 AV-20	15	1	1	16	15	0.09×10^8
Horizontal		1	2	8	8	0.06×10^8
		2	1	16	4	0.6×10^8
		2	2	8	2	1.06×10^8

TABLE III. DATA SUMMARY - 28 Vdc AIRFRAME RELAY (Continued)

RUN NUMBER	FIBER LENGTH	HEIGHT CODE	TYPE CODE	#TARGETS	#FAILURES	<E> f sec/m^3
AV-18 AV-19	15	1	1	16	8	$.18 \times 10^8$
Vertical		1	2	8	6	$.18 \times 10^8$
		2	1	16	1	1.68×10^8
		2	2	8	0	$\geq .84 \times 10^8$
AV-21 AV-24	3.5	1	1	16	3	1.33×10^8
Horizontal		1	2	8	2	1.87×10^8
		2	1	16	0	$\geq 3.92 \times 10^8$
		2	2	8	1	3.62×10^8
AV-22 AV-23	3.5	1	1	16	0	$\geq 7.84 \times 10^8$
Vertical		1	2	8	0	$\geq 3.92 \times 10^8$
		2	1	16	0	$\geq 7.84 \times 10^8$
		2	2	8	0	$\geq 3.92 \times 10^8$

TABLE IV. 115 Vac AIR FRAME RELAY
DATA SUMMARY

HEIGHT CODE

1. $I \leq 10$ ma

2. $I > 10$ ma

TYPE CODE

1. Short to Adjacent Terminal

2. Short Across Insulating Barrier

V_o - 115 Vac 400 Hz

RUN NUMBER	FIBER LENGTH	HEIGHT CODE	TYPE CODE	#TARGETS	#FAILURES	<E> f sec/m^3
AV-25 AV-28	7	1	1	16	15	$.08 \times 10^8$
Horizontal		1	2	8	8	$.08 \times 10^8$
		2	1	16	10	$.24 \times 10^8$
		2	2	8	2	2.08×10^8
AV-26 AV-27	7	1	1	16	16	$.18 \times 10^8$
Vertical		1	2	8	7	$.45 \times 10^8$
		2	1	16	6	$.30 \times 10^8$
		2	2	8	6	$.03 \times 10^8$
AV-29 AV-32	15	1	1	16	16	$.03 \times 10^8$
		1	2	8	8	$.02 \times 10^8$
		2	1	16	16	$.06 \times 10^8$
		2	2	8	8	$.08 \times 10^8$

TABLE IV. 115 Vac AIR FRAME RELAY DATA SUMMARY (CONTINUED)

RUN NUMBER	FIBER LENGTH	HEIGHT CODE	TYPE CODE	#TARGETS	#FAILURES	<E> f sec/m³
AV-30 AV-31	15	1	1	16	16	$.03 \times 10^8$
Vertical		1	2	8	8	$.02 \times 10^8$
		2	1	16	13	$.12 \times 10^8$
		2	2	8	7	$.12 \times 10^8$
AV-33 AV-36	3.5	1	1	16	10	$.39 \times 10^8$
Horizontal		1	2	8	7	$.24 \times 10^8$
		2	1	16	4	1.27×10^8
		2	2	8	0	$\geq 2.54 \times 10^8$
AV-34 AV-35	3.5	1	1	16	10	$.69 \times 10^8$
Vertical		1	2	8	3	1.66×10^8
		2	1	16	1	5.91×10^8
		2	2	8	0	$\geq 2.88 \times 10^8$

The amount of current flow and the time length of that current flow was available in the experimental data from the chart recorder. These data can be found in Appendix B.

IV. GENERAL AVIATION COMPONENTS

A. Selection Criteria

The targets selected from the general avionics field were a distance measuring instrument, a transponder, and communication equipment. The rationale applied in selecting the equipment used as targets involved the projected wide use in the next decade, and a moderate price tag. Based on the results of some avionics equipment surveys, the NARCO DME 190 TSO and the Collins transponder TDR-90 were selected. Five separate targets were selected which were considered representative of the full range of communication equipment. These were a NARCO COM-120, GENAVE G-100, GENAVE G-1000, King KY-92, and EDO-AIR RT-661A. No consideration of the vulnerability of the item itself was used in the selection criteria.

B. Target Description

1. DME 190 TSO. The NARCO DME 190 TSO, which was selected for testing, was a 100% solid-state DME. The instrument has a full 200 channels and a 200-mile range. The specifications of the DME are listed in Table V. The cooling was ram air (forced air).

2. TDR-90. The TDR-90 transponder replies to all valid ATC radar interrogations with a coded reply signal. This signal is used by the ATC controller to locate and identify the transponder-equipped aircraft. The TDR-90 transmits on a frequency of 1090 MHz and receives on a frequency of 1030 MHz. There are 4096 identification codes. A side lobe suppression system (SLS) is included and it prevents triggering by the side-lobe radiation from the secondary surveillance radar (SSR). There was no forced air cooling.

3. Communication Equipment. The five communications modules, which were selected for testing, were wired for use in a 12 volt system. The important specifications of each set are listed in Table VI. The GENAVE G-1000 was a Com-Nav unit, however, only the communications part was tested. All units were solid-state circuitry. None of the units had forced air cooling.

C. Data Acquisition

1. DME 190 TSO. There were two monitoring methods for the DME. The first was strip chart, recording the DME input voltage and current. The second was a visual monitoring of the DME outputs. During the exposure, the DME operation was checked by a test bench setup, ATC-600. The specifications for this system can be found in Appendix C. The

TABLE V. DME 190 TSO SPECIFICATIONS

Power requirements	13.75v/3 amps... 27.5v/1.6 amps
Transmitter frequency band	1041 to 1150 MHz (paired with 108.00 to 117.95 NAV CHANNELS)
Transmitter power	100 watts nominal, 80 watts minimum
Transmitter frequency stability	± .01%
Number of channels	200 (includes both X and Y)
Control	2 out of 5 ARINC (Remote Channeling optional)
Receiver frequency	978 to 1213 MHz (Paired with 108.00 to 117.95 NAV Channels)
Receiver sensitivity	-82 dBm, minimum
Acquistion time, including channeling	1 second, nominal
Range	0 to 199.9 nautical miles
Memory	6 to 8 seconds
Ident Audio Output (P901-5)	45 MW nominal into 300 ohms
Digital Outputs	RNAV compatible with Narco RNAV and others
Accuracy	± 0.1 nautical mile typical, 0.2 nautical miles max
Ground Speed	0 to 400 knots ± 5%
Time-To-Station	0 to 89 minutes ± 5%/± 1 minute

TABLE VI. COMMUNICATIONS EQUIPMENT SPECIFICATIONS

MFG		KING	GENAVE	GENAVE	EDO-AIRE	NARCO
MODEL		KY92	ALPHA-100	ALPHA-1000	RT-661-A	COM 120
WEIGHT		1.27 Kg	1.82 Kg	2.04 Kg	1.50 Kg	1.59 Kg
NO. OF CHANNELS		720	100	720	720	720
CHANNELS SEPARATION		25 KHz	100 KHz	25 KHz	25 KHz	25 KHz
FREQENCY RANGE		118.000 to 135.975 MHz	118.0 to 127.9 MHz	118.000 to 135.975 MHz	118.000 to 135.975 MHz	118.000 to 135.975 MHz
OUTPUT POWER		7 watts	4 watts	7 watts	6 watts	8 watts
INPUT POWER	Receive	0.4 amps	0.5 amps	0.8 amps	0.6 amps	0.6 amps
	Transmit	4.5 amps	1.5 amps	4.0 amps	3.0 amps	3.5 amps

ATC-600 can be initialized for a preset velocity and distance. The DME then would interrogate the test setup and from the response, calculate the distance, velocity, and time to arrival. These velocities and distances were chosen to provide a time which would end at the time the exposure was finished [20-30 min.]. During the exposure, one output could be monitored either distance, velocity, or time. The one that was monitored was the one that would change and require updating (time or distance). The transmissions between the DME 190 and the ATC-600 Test Set were via antenna, and not hardwired.

2. TDR-90. The TDR-90 Collins Transponder unit was placed in the experimental chamber and the 613L-3 control unit [a completely airtight unit] was located outside the exposure chamber in the experimental control area. The transponder unit is convectively cooled with 3mm openings at the top, bottom, and both sides. The unit was placed on the table completely exposed to the carbon fiber cloud. During its normal use, this unit would be mounted under the control console in the cockpit, partially shielded from a carbon fiber cloud. The transponder test circuit setup included the transponder unit (TDR-90), the control unit (613L-3), and a ramp use test set (ATC-600). The test unit is used to transmit an interrogation of the pilot's code to the transponder. The pilot's code, which has been selected on the control unit, is displayed by the ATC-600. The link used was via an antenna, not hardwired.

3. Communication Equipment. There were two types of monitoring done during these tests. The input voltage and current were monitored using a strip chart recorder. This monitoring would show any unusual current flow or voltage change. The other monitoring performed was a check by testing personnel of a unit's ability to transmit and receive an audible signal. A communication unit was placed at a remote station outside the exposure chamber. This location was 100 yds from the exposure chamber, shielded by three walls. The microphone and antenna for each unit being exposed was outside the exposure chamber. The individual test consisted of transmitting and receiving at two frequencies, 118 MHz and 127 MHz. An audible transmission and reception between the unit under test and the remote station was judged by the testing personnel. As a final check of each unit at the termination of a trial, each individual module was used to contact Phillips Airfield Tower on the frequency 123.5 MHz. This tower was located approximately 0.3 mi from the test area.

D. Test Procedure and Failure Criteria

1. DME 190 TSO. Because of the ram air cooling required with the DME, all vulnerability tests used the supplied cooling kit. Figure 6 shows how the DME was exposed to CF during testing. The air scoop was placed in the exposure chamber and air drawn through the system at the required cooling rate.

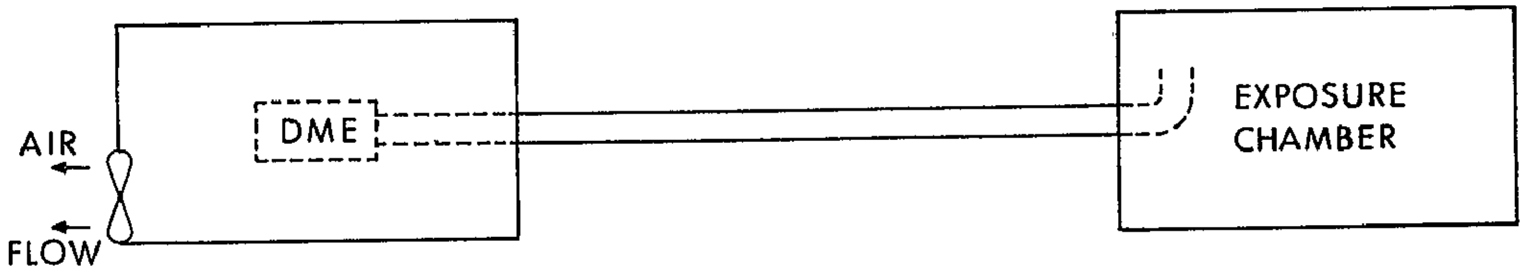

Figure 6. Exposure Setup for DME

The chambers used were both the flow through and the small free fall. The exposure used to calculate the <E> was that provided by a ball gauge in the exposure chamber. The fibers used were 1mm, 3.5mm, and 7.0mm of Hercules AS.

Because the DME testing was conducted in two different chambers, it is necessary to describe shortly each trial and its setup.

Run #1

This trial was performed in the flow through chamber. The DME had two-sided sticky tape inside to show penetration of CF into the DME. The sticky samples showed CF penetration, however, there was no failure.

Run #2

This trial was a repeat of Run #1 without the sticky tape inside. Again there were no failures.

Runs #616, #617, and #618

These trials are the first ones performed in the small free fall chamber. The DME was in the enclosure box. During this test, sticky cylinders were placed at the exhausts of the DME. These sticky cylinders showed that fibers are transmitted through the DME; however, there were no failures.

Runs #619 and #620

The object of these trials was to measure the transfer function of CF through the DME. The exposure was measured in the exposure box and at the exhaust of the DME chamber by ball gauge detectors. The measured transmission factor through the DME instrument was defined to be:

$$\frac{E_{B1}}{E_{B2}} = \text{Transmission factor}$$

where E_{B1} and E_{B2} are the exposures measured in the DME box and in the free ball chamber, respectively. The measured transmission factors were 4.6×10^{-3} for 7mm fibers and 1.3×10^{-2} for 3.5mm fibers during runs 619 and 620, respectively.

Failure was defined to be a noticeable change in the output of the DME. During the complete series of tests no changes were observed. Between tests, the cleaning process consisted of a complete disassembly of the unit and a thorough cleaning using a vacuum cleaner, brush, and a high velocity air jet. The system was then stepped through a complete on-off cycle several times.

2. TDR-90. The transponder was placed in the center of a table in the middle of the S-280 experimental chamber. The fibers used were 3.5 mm, 7.0mm, and 10.0mm of Hercules AS. Ball monitors were used to measure exposure at the extremes of the table. The exposure used in the calculation of vulnerability is the average of the two detectors.

The pilot's ID code was set at 1111. This number was selected because it was the lowest possible number and any change could be easily observed. The setup was allowed to run 5 minutes to insure its proper operation before beginning the carbon fiber exposure. Any noticeable difference in the operation of the transponder unit was considered a failure. The time of the failure was noted. After each exposure, the case was removed from the transponder and the complete system was cleaned using a high velocity air jet and a vacuum cleaner sequentially. The system was then operated through a complete off-on cycle five times. This assured minimal effects from residual fibers.

3. Communication Equipment. Careful examination of the communication units revealed that the transfer of fibers into the units would be very low. Because of this, the units were exposed in the large free fall chamber without their chassis covers. The visible electronics were always exposed to the falling fiber. In the case of units which had visible electronics or connections on two sides, each side was exposed for two trials. All units were operated at full power during an exposure.

The chamber was equipped with a free fall dispenser unit and two charge transfer ball detectors, one on each wall. The exposure used in the vulnerability calculations was the average of the two detectors at the time of failure. All the trials were made with 3.5mm Hercules AS fibers.

Because on-line monitoring of the units was impossible during an exposure, it became necessary to use a different exposure technique. There were five trials, each having a total exposure of 2-3 x 10^7 f-sec/m^3. During each trial, four units were exposed to carbon fibers and the fifth was used as the monitoring station outside the chamber. Each trial consisted of approximately 25 separate segments. Each segment consisted of an exposure between 0.5 and 1.0 x 10^6 f-sec/m^3 followed by a test of each unit for proper operation at the two designated frequencies.

E. Data Analysis

1. DME 190 TSO. During the complete series of tests with the DME, there were no observable malfunctions. Table VII is a summary of the data as analyzed using the theory of Maximum Likelihood Estimate as explained in Appendix A.

2. TDR-90. Table VIII gives a summary of the transponder data. During approximately 20% of the tests, there was a failure. The <E> increases with fiber length because of the fiber transfer through the vent holes in the transponder chassis.

3. Communication Equipment. The <E> for the communication units can be found in Table IX. This <E> is generated without regard to which side was directly exposed to the fibers. It should be noted here that the <E> generated in these trials should be increased at least a factor of 10 when the units are in their proper enclosures.

V. AIRPORT SURVEILLANCE RADAR, ASR-3

A. Selection Criteria

Table X is a summary of airport surveillance radars used in the field in 1977. The ASR-3 system was selected because it was being replaced in the field and units were easily available. Because of the vacuum tube technology and the large airflow required for cooling, it was considered to provide a worst case test. It was, however, generic: enclosures were similar to the enclosures of the other radar units, and the building enclosures and air circulation systems were similar. The purpose of these tests was to determine if any vulnerability existed, and if so, the degree of vulnerability.

B. Target Description

The ASR-3 is a fixed airport surveillance radar system which provides a visual presentation of the location of aircraft within a maximum airport terminal area of 50 nautical miles radius. The aircraft position information is displayed on a plan-position indicator (PPI) which permits airport traffic controllers to observe aircraft within the specific range of the set and to aid in directing the course of the aircraft by means of airport radio communications. This same information can be used with any ground control approach (GCA) radar system to direct aircraft into the landing pattern for a GCA landing.

The ASR-3 uses a magnetron oscillator to generate the radar output which is transmitted by the antenna. The reflected signal is received by the antenna which rotates 360° for coverage of the airport terminal area. This signal is fed into the receiver unit for proper conversion and display as video information on the PPI. In order to provide the maximum reliability of the radar unit, two identical transmitters and receivers are supplied. Each set constitutes a single complete channel of operation. Either channel can be used as the operating channel while the other is in standby or being serviced. This provides a continuously operating system.

TABLE VII. DATA SUMMARY FOR DME 190 TSO

Item - DME

Manufacturer - NARCO AVIONICS

Model - DME 190 TSO

FIBER	LENGTH MM	OPERATION MODE	NO. OF TESTS	NO. OF FAILURES	<E>
AS	1	ON	2	0	$\geq 5.7 \times 10^7$
AS	3.5	ON	3	0	$\geq 5.39 \times 10^7$
AS	7	ON	2	0	$\geq 6.7 \times 10^7$

TABLE VIII. DATA SUMMARY FOR TRANSPONDER TDR-90

Item - Transponder

Manufacturer - Collins

Model - TDR-90

FIBER	LENGTH MM	OPERATION MODE	NO. OF TESTS	NO. OF FAILURES	<E>
AS	3.5	ON	12	3	0.96×10^8
AS	7.0	ON	12	2	1.0×10^8
AS	15.0	ON	12	1	2.4×10^8

TABLE IX. DATA SUMMARY FOR COMMUNICATION EQUIPMENT

MANUFACTURER	MODEL	OPERATION MODE	FIBER LENGTH (mm)	FIBER TYPE	NO OF TESTS	NO OF FAILURES	<E>
KING	Ky-92	Xmit	3.5	Hercules AS	6	1	1.3×10^{8}
		Receive	3.5	Hercules AS	6	0	$\geq 1.3\times10^{8}$
GENAVE	G-100	Xmit	3.5	Hercules AS	5	1	1.4×10^{8}
		Receive	3.5	Hercules AS	5	1	1.4×10^{8}
GENAVE	G-1000	Xmit	3.5	Hercules AS	7	1	1.3×10^{8}
		Receive	3.5	Hercules AS	7	3	0.5×10^{8}
EDO AIRE	RT661-A	Xmit	3.5	Hercules AS	4	0	$\geq 1.4\times10^{8}$
		Receive	3.5	Hercules AS	4	0	$\geq 1.4\times10^{8}$
NARCO	Com-120	Xmit	3.5	Hercules AS	7	0	$\geq 1.4\times10^{8}$
		Receive	3.5	Hercules AS	7	3	0.5×10^{8}

Table X.* 1977 Airport Surveillance Radar Units Summary

Radar	Number in use	Highest Voltage	P_{av}	P_{peak}	Output Tube	Electronic Type
ASR-3	19	24 kv	400W	400KW	Magnetron	Mostly tube
ASR-4, 5,6	70	24 kv	400W	400Kw	Magnetron	Mostly tube, Hybrid
ASR-7	39	24 kv	400W	400Kw	Magnetron	Hybrid
ASR-8	30	70 kv	600W	1MW	Klystron	All solid state except Klystron

*Information from Chuck Koldhausen, Radar Section FAA, HQ Section.

The equipment for the ASR-3 radar set is housed at three separate sites; the local site, the remote site, and the repeater site. The central position is the remote site and the other two sites must be located within 1.7 nautical miles, the maximum cable length provided, from remote site.

The local site is the principle unit of the radar set. This site is composed of a building which houses the transmitter and receiver cabinets for both channels, the ac voltage regulation, and the beam switching systems with its associated waveguide network. The antenna tower is located at the local site immediately outside the building. The remote site is located in or near the airport control tower and is used to house the radar output equipment. Included among the units are the console equipment, video mapping assemblies, ac regulator, cable junction box, and the power distribution box. The repeater site contains the Repeater Console equipment and an additional Console Assembly. A list of the systems specifications is given in Appendix D.

C. Data Acquisition

Most of the monitoring of the radar set was done using strip chart recorders. When the transmitter cabinet was undergoing tests, there were nine signals monitored on the strip chart recorders. These were the transmitter voltage and current, the magnetron current, the voltage levels of the four dc voltages in the cabinet, 280, +120, -150, and 28v dc, the relative tuning, and the power output. There were 15 signals monitored during the receiver tests. They were the voltage and current outputs of the dc power supplies housed in the receiver cabinet. The power supplies monitored were +280V, four 120V, 150V, +300V, and the voltage alone for the 28V. Because it was not possible to monitor some radar set outputs with a strip chart monitor, two video tape monitor units were used in order to have a visual record. The first unit monitored two CRT displays, one of which viewed the video output and the Moving Target Indicator (MTI), and the other viewed the thyratron trigger and the high voltage test pulse. The second video unit was used to monitor the transmitter output monitoring meters. These included the transmitter high voltage and current and magnetron current. Also monitored from the face of the transmitter cabinet were the Keep Alive current, AFC Crystal current, and Signal Crystal current along with the radar performance indicator lights and most of the power supply fuses. In the same video unit record was a clock for easy data correlation.

D. Test Procedure

Figure 7 shows the setup for the venturi action fiber dispenser and the position of the fiber detectors used. The exposure to failure is measured using the ball gauge in the center of the input duct connected to the cabinet under test. Failure for these tests was defined as the radar set failure to transmit or receive and process the echo box's signals. The fibers used were 7mm Hercules HMS.

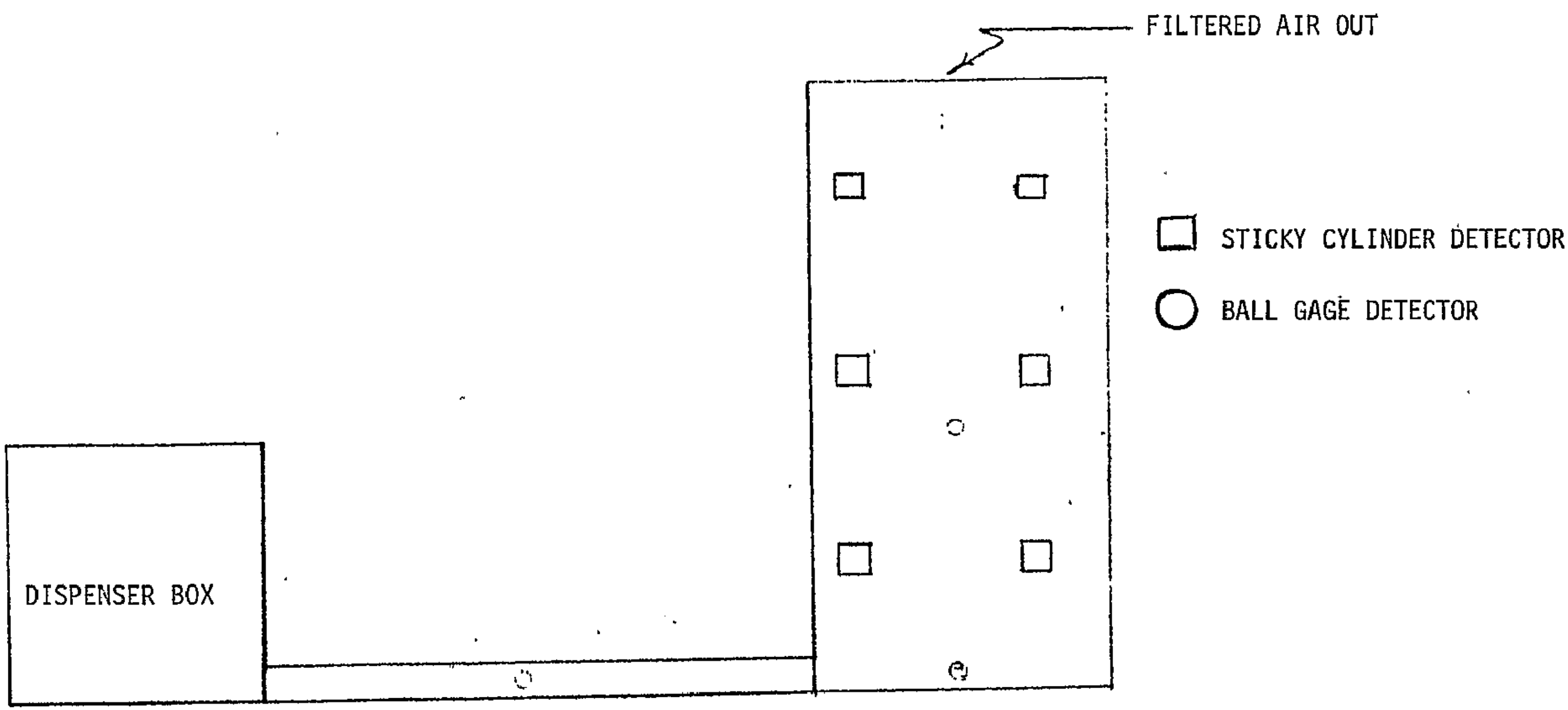

Figure 7. Exposure Setup for ASR-3

1. Radar Set Operation. Because of the lack of an antenna as a load for the radar set, the exposures of the unit were accomplished while the system was being operated into a dummy load. Also attached to the transmitter output was an Echo box. This box when tuned to the radar output frequency showed the radar set's output power and also produced an echo signal to the receiver for checking proper operation of the receiver and target identification electronics. During operation, the output of the echo box was monitored by the video tape unit. Before each test the radar set was activated and allowed to operate approximately 0.5 hours.

2. Transmitter Cabinet Test. For the transmitter tests, the fibers were fed from the dispensing box into a 6 inch diameter duct connected to the transmitter cabinet air input. The path was through the input filter section and up through the transmitter cabinet and out the exhaust at the top of the cabinet. These exhausts were covered with filter material to prevent the escape of carbon fibers into the testing area.

3. Receiver Cabinet Test. The receiver tests were performed in much the same manner; however, there were two air inputs and filter units to the receiver cabinet. Both inputs were tested separately. The fiber passage was through the filter area and up the center of the receiver cabinet. This was the area where there were many exposed terminals associated with the many low voltage, high current power supplies used in the radar set.

4. Test Termination, Cleanup and Return to Service Criteria. Because of the controlled fiber dissemination method used in these tests, it was possible to perform the tests with a minimum amount of fiber exposure to the item under test. The upper level of exposure interest was on the order of 10^7f-s/m^3. Tests were terminated when a failure occurred or at 2-3 x 10^7 f-s/m^3 if no failures occurred. After the test was completed, the cabinet under test was completely cleaned using vacuum cleaners, a high flow stream of air, and brushes.

The return to service criteria for further testing was to have the complete radar set cycled three times. Each cycle required the radar set to go from a full off to a fully operational mode for 15 minutes. If during a recycling period any failure occurred, the cabinet which had been tested would be completely cleaned again and the recycling process begun anew. This was done to minimize the possible effects of residual carbon fibers. If any residual carbon fiber effects existed, they could also be seen from a downward trend in the exposure to failure data.

5. Added Tests. Because the ASR-3 radar set was meant to be a generic target for predicting vulnerability in the field, it was decided to test the radar set without its input filters. The purpose of this type of testing is to provide an <E> for a radar set which can then be

corrected by measuring a filter transmission factor separately and combining the data to predict the effects to the system of an outside exposure, E. The measured filter transmission for the ASR-3 filter (AMER-GLAS, 10x10x1, FSN 4130-00-542-4482) averaged over the range of air velocities (250FPM to 750FPM) found in the radar set was approximately 0.5%.

E. Data Analysis

The exposure used to compute <E> was the input exposure. The transmitter tests with the input filters in place produced no failures. Without the filters, there was a failure every time. The receiver failures occurred during the first five tests with input filters. It cannot be explained why the system stopped failing with filters after the fifth trial. Tables XI and XII show the mean exposure to failure, <E>, for the transmitter and receiver cabinets, respectively.

F. Residual Fiber Effects

After the tests were completed on the ASR-3 unit, the system was cleaned with a vacuum cleaner and the set was operated. This operation included 100 hours of operating time. During these tests the radar unit was completely recycled 15 times. There were no failures during the entire test.

VI. CONCLUSIONS

1. The vulnerability of aircraft cannot be predicted using the vulnerability numbers for Burndey block terminals and relay terminals. The effect, if any, of a 1 to 10ma current draw at a terminal would have to be assessed by the aircraft manufacturers. There would be no effect on the low impedance output of a power supply, however, there may be some effect on a digital signal or a high impedance voltage source.

2. The vulnerability of general avionics equipment is low. The TDR-90, which proved to be vulnerable, was tested in a worst case scenario. Its exposure to failure would be increased by a factor of 10 if the equipment were shielded as it is in an aircraft.

3. The DME is not vulnerable to the CF threat.

4. General aviation communication equipment has a very low vulnerability to carbon fibers. The <E> established by these experiments should be increased by a factor of 50 because of the fiber transfer function of the unit's case and the unit's position in the control console of the aircraft.

TABLE XI. DATA SUMMARY OF ASR-3 TRANSMITTER CABINET

Item - ASR-3 Transmitter Cabinet
Manufacturer - Bendix Corporation
Model - ASR-3

FIBER	LENGTH MM	OPERATION MODE	NO. OF TESTS	NO. OF FAILURES	$<E_o \frac{F\text{-sec}}{m^3}$
HMS	7.5	On (with input filters)	4	0	$\geq 9.3 \times 10^7$
HMS	10	On (with input filters)	1	0	$\geq 1.5 \times 10^7$
HMS	7.5	On (without input filters)	5	5	3.02×10^6

TABLE XII. DATA SUMMARY FOR ASR-3 RECEIVER CABINET

Item - ASR-3 Receiver Cabinet
Manufacturer - Bendix Corporation
Model - ASR-3

FIBER	LENGTH MM	OPERATION MODE	NO. OF TESTS	NO. OF FAILURES	$<E_o \frac{F\text{-sec}}{m^3}$
HMS	7.5	On (with input filters)	8	4	5.04×10^7
HMS	7.5	On (without input filters)	8	8	7.8×10^5

5. The tests of the ASR-3 radar unit showed a slight vulnerability of the system exposed directly to carbon fibers. The vulnerability of a radar unit in place would be much less because of the loss of exposure due to the transmission factor through buildings and air handling systems. The effect of carbon fibers on the feed horn of the radar unit was not studied.

6. The decontamination method used for all tested equipment required the item be vacuumed and brushed well. The return to service criteria required that the instrument operate perfectly for 0.5 hours after cleaning. In all tests, the equipment was immediately restored to proper operating conditions and there was never any damage which required a repair.

7. The ASR-3 after its final test was cleaned and allowed to operate 100 hours. During these operations, the complete unit was cycled 15 separate times. There were no failures. The unit always reached a fully operational mode. Residual carbon fiber affects were not observed.

ACKNOWLEDGEMENTS

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APPENDIX A*

Derivation of the Maximum Likelihood Estimate of the Mean
for an Exponential Failure Distribution

Jill H. Smith

Extracted from BRL Report No. ARBRL-TR-02205, "Vulnerability Model Validation Testing - Project HAVE NAME (U)", E. M. Vogel and J. H. Smith, December 1979, SECRET.

The exposure to failure distribution for a single fiber kill is

$$F(E) = 1 - e^{-E/\lambda}$$

and therefore has density function

$$f(E) = 1/\lambda e^{-E/\lambda}$$

To obtain the best estimate of the mean, λ, the method of maximum likelihood is used. The likelihood function, L, is the probability of obtaining certain outcomes in a sample and by definition is the product of the density functions.

Therefore, if we have m failures out of n tests, the likelihood function is

$$L = \prod_{i=1}^{m} (1/\lambda e^{-E_i/\lambda}) \prod_{i=m+1}^{n} (e^{-E_i/\lambda})$$

$$= (1/\lambda^{m} e^{-\sum_{i=1}^{m} E_i/\lambda}) (e^{-\sum_{i=m+1}^{n} E_i/\lambda})$$

$$= (1/\lambda^{m} e^{-\sum_{i=1}^{n} E_i/\lambda})$$

Maximizing the likelihood function, we find the most likely value for λ, the mean. Maximizing the natural log of the function is equivalent to maximizing the function itself, therefore,

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$$\ell(\lambda) = \ln(L) = -m\ln\lambda - \frac{1}{\lambda}\sum_{i=1}^{n} E_i$$

$$\frac{d\ell(\lambda)}{d\lambda} = -\frac{m}{\lambda} + \frac{1}{\lambda^2}\sum_{i=1}^{n} E_i$$

$$0 = \frac{-m}{\hat{\lambda}} + \frac{1}{\hat{\lambda}^2}\sum_{i=1}^{n} E_i$$

$$\hat{\lambda} = \sum_{i=1}^{n} E_i/m$$

The mean exposure to failure, $\hat{E} = \hat{\lambda}$, is therefore the total test exposure divided by the number of failures.

What happens when E is large and the number of failures, m is zero?

$$\lim_{m=o} \hat{\lambda} = \infty$$

$$1 - e^{-E/\hat{\lambda}} = 0 \quad \text{as} \quad \hat{\lambda} \to \infty$$

As we have no failures with which to estimate the parameter λ we can only say we have less than one (< 1) failure and therefore

$$\hat{E} = \sum_{i=1}^{n} E_i/{<1}$$

$$\hat{E} = \sum_{i=1}^{n} E_i$$

Confidence Limits for the Exposure to Failure

$$2m\frac{\hat{E}}{\bar{E}} \sim \chi^2\,(2m) \text{ where all tests result in a failure.} \quad \text{(Appendix A)}$$

Thus, it follows that

$$P\left\{\chi^2_{\alpha/2}\,(2m) \leq \frac{2m\hat{E}}{\bar{E}} \leq \chi_{1-\alpha/2}\,(2m)\right\} = 1-\alpha$$

where χ^2_α is the $100\alpha^{th}$ percentile of the χ^2 distribution. Therefore,

$$P\left\{\frac{2m\hat{E}}{\chi_{1-\alpha/2}\,(2m)} \leq \bar{E} \leq \frac{2m\hat{E}}{\chi^2_{\alpha/2}\,(2m)}\right\} = 1-\alpha$$

The interval $\dfrac{2m\hat{E}}{\chi_{1-\alpha/2}(2m)}$ to $\dfrac{2m\hat{E}}{\chi^2_{\alpha/2}\,(2m)}$ covers the true mean exposure to failure, $\bar{E}$, with probability $1-\alpha$.

When there is at least one test that does not fail and we truncate on exposure, we have the conservative two sided confidence interval

$$P\left\{\chi^2_{\alpha/2}\,(2m) < \frac{2m\hat{E}}{\bar{E}} < \chi^2_{1-\alpha/2}\,(2m+2)\right\} = 1-\alpha \qquad [3]$$

That is,

$$P\left\{\frac{2m\hat{E}}{\chi^2_{1-\alpha/2}(2m+2)} < \bar{E} < \frac{2m\hat{E}}{\chi^2_{\alpha/2}\,(2m)}\right\} = 1-\alpha$$

And in the case where there are no failures, m=0, we can conservatively say that

$$P\left\{\bar{E} > \frac{2\hat{E}}{\chi^2_{1-\alpha}\ (2)}\right\} > 1-\alpha$$

Examples

Applying the above methodology to example data, we compute the point estimates of the exposures to failure and then use the point estimate to construct the confidence limits for the exposures to failure.

The same values of E_i are used in each example to illustrate the effect of "no malfunction" (runs that did not fail), on $\hat{E}$.

Example 1.

Item A is tested five (5) times and malfunctions (fails) every time at the E_i shown.

Test Number	E_i (fs/m^3)
1	1×10^6
2	1×10^7
3	5×10^6
4	5×10^6
5	8×10^6
n = 5	m = 5

$$\hat{E} = \frac{\sum_{i=1}^{n} E_i}{m} = \frac{2.9 \times 10^7}{5}$$

$$\hat{E} = 5.8 \times 10^6 \text{ fs/m}^3$$

Using this point estimate for the exposure to failure, we construct the confidence bounds for the true exposure to failure.

$$P\left\{\frac{2m\hat{E}}{\chi^2_{1-\alpha/2}\ 2m} \leq \bar{E} \leq \frac{2m\hat{E}}{\chi^2_{\alpha/2}\ 2m}\right\} = 1-\alpha$$

Substituting, we have

$$P\left\{\frac{(10)(5.8 \times 10^6)}{20.48} \leq \bar{E} \leq \frac{(10)(5.8 \times 10^6)}{3.25}\right\} = 0.95$$

$$P\{2.83 \times 10^6 \leq \bar{E} \leq 1.78 \times 10^7\} = 0.95$$

Therefore the interval 2.83×10^6 to 1.78×10^7 fs/m^3 will cover the true exposure to failure, $\bar{E}$, with probability .95.

Example 2

Item B is tested five (5) times and malfunctions on three (3) tests. On the two tests where there were no malfunctions, the tests were terminated at the E_i shown

Test Number	E_i (fs/m^3)	
1	1×10^6	
2	1×10^7	no malfunction
3	5×10^6	
4	5×10^6	
5	8×10^6	no malfunction
n = 5	m = 3	

$$\hat{E} = \frac{\sum_{i=1}^{n} E_i}{m} = \frac{2.9 \times 10^7}{3}$$

$$\hat{E} = 9.7 \times 10^6 \text{ fs/m}^3$$

Using this point estimate for the exposure to failure, we construct the confidence bounds for the true exposure to failure.

$$P\left\{\frac{2m\hat{E}}{\chi^2_{1-\alpha/2}\ (2m+2)} < \bar{E} < \frac{2m\hat{E}}{\chi^2_{\alpha/2}\ 2m}\right\} = 1-\alpha$$

Substituting, we have

$$P\left\{\frac{6(9.7 \times 10^6)}{17.53} \leq \bar{E} \leq \frac{6(9.7 \times 10^6)}{1.24}\right\} = 0.95$$

$$P\ \{3.32 \times 10^6 \leq \bar{E} \leq 4.69 \times 10^7\} = 0.95$$

That is, the interval 3.32×10^6 to 4.69×10^7 fs/m^3 covers the true exposure to failure with probability .95.

Example 3

Item C is tested five (5) times and does not malfunction (fail) on any test. The tests were terminated at the E_i shown

Test Number	E_i(fs/m^3)	
1	1×10^6	no malfunction
2	1×10^7	no malfunction
3	5×10^6	no malfunction
4	5×10^6	no malfunction
5	8×10^6	no malfunction
n = 5	m = 0	

$$\hat{E} > \sum_{i=1}^{n} E_i = 2.9 \times 10^7$$

Using this point estimate for the exposure to failure, we construct a conservative (as though there was one failure) one-sided confidence bound.

$$P\left\{\bar{E} > \frac{2\hat{E}}{\chi^2_{1-\alpha}(2)}\right\} > 1-\alpha$$

That is $\bar{E} > 9.69 \times 10^6$ with at least 95% probability.

APPENDIX B

SUSTAINED CURRENT FLOW DATA

Tables B1, B2, and B3 are the highlights of the sustained current flow data during the airframe relay exposure trials. A sustained current flow was defined as current flow for a period of longer than 30 seconds. The tables list the maximum time and maximum current for shorts between adjacent terminals (Code 1), and between terminals across an insulating barrier (Code 2). Also shown in the tables is the maxiumum length of time current is drawn from the power supply and the maximum amount of current drawn from the power supply. The exposure listed is that recorded at the beginning of the sustained current flow.

TABLE B-I   Sustained Hit Data for 3.5mm Fibers

Code: 1. Return Adjacent Terminal   2. Return Across Barrier   3. Main Power Output

RUN NUMBERS	VOLTAGE	CODE	ORIENTATION	MAX TIME SHORT		MAX CURRENT SHORT		EXPOSURE @ START
				TIME(sec)	I(ma)	TIME(sec)	I(ma)	[f-sec/m^3]
AV-21 AV-24	28VDC	1	Horizontal	560	9			.306 x 10^7
						560	9	.306 x 10^7
		2		595	10			1.670 x 10^7
						595	10	1.670 x 10^7
		3		1505	20			.306 x 10^7
						1505	20	.306 x 10^7
AV-22 AV-23	28VDC	1,2,and 3	*					
AV-33 AV-36	115VAC	1	Horizontal	105	8			1.983 x 10^7
						105	8	1.983 x 10^7
		2						
		3		105	30			1.983 x 10^7
						105	30	1.983 x 10^7
AV-34 AV-35	115VAC	1,2,and 3						

*There were no shorts providing measurable current greater in length than 30 sec.

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TABLE B-II Sustained Hit Data for 7.0mm Fibers

Code: 1. Return Adjacent Terminal 2. Return Across Barrier 3. Main Power Output

RUN NUMBERS	VOLTAGE	CODE	ORIENTATION	MAX TIME SHORT TIME(sec)	MAX TIME SHORT I(ma)	MAX CURRENT SHORT TIME(sec)	MAX CURRENT SHORT I(ma)	EXPOSURE @ START [$f\text{-}sec/m^3$]
AV-13 AV-15	28 VDC	1	Horizontal	1060	15			$.820 \times 10^7$
						365	20	$.499 \times 10^7$
		2		990	10			$.832 \times 10^7$
						685	10	1.759×10^7
		3		1605	22			$.820 \times 10^7$
						810	30	$.499 \times 10^7$
AV-14 AV-16	28 VDC	1	Vertical	155	5			1.534×10^7
						155	5	1.534×10^7
		2		1060	3			$.703 \times 10^7$
						1060	3	$.703 \times 10^7$
		3		1065	3			$.703 \times 10^7$
						155	5	1.534×10^7

TABLE B-II Sustained Hit Data for 7.0mm Fibers (con't)

Code: 1. Return Adjacent Terminal 2. Return Across Barrier 3. Main Power Output

RUN NUMBERS	VOLTAGE	CODE	ORIENTATION	MAX TIME SHORT TIME(sec)	MAX TIME SHORT I(ma)	MAX CURRENT SHORT TIME(sec)	MAX CURRENT SHORT I(ma)	EXPOSURE @ START [f-sec/m^3]
AV-25 AV-28	115VAC	1	Horizontal	745	20			$.868 \times 10^7$
						745	20	$.868 \times 10^7$
		2		690	10			$.340 \times 10^7$
						690	10	$.340 \times 10^7$
		3		700	20			$.340 \times 10^7$
						345	30	$.145 \times 10^7$
AV-26 AV-27	115VAC	1	Veritcal	265	5			$.623 \times 10^7$
						110	21	1.33×10^7
		2		70	8			$.978 \times 10^7$
						40	15	1.519×10^7
		3		705	35			$.76 \times 10^7$
						705	35	$.76 \times 10^7$

TABLE B-III Sustained Hit Data for 15mm fibers

Code: 1. Return Adjacent Terminal 2. Return Across Barrier 3. Main Power Output

RUN NUMBERS	VOLTAGE	CODE	ORIENTATION	MAX TIME SHORT TIME(sec)	MAX TIME SHORT I(ma)	MAX CURRENT SHORT TIME(sec)	MAX CURRENT SHORT I(ma)	EXPOSURE @ START [f-sec/m^3]
AV-17 AV-20	28VDC	1	Horizontal	1595	20			$.465 \times 10^7$
						1595	20	$.465 \times 10^7$
		2		1740	2			$.169 \times 10^7$
						505	18	$.459 \times 10^7$
		3		1945	30			$.233 \times 10^7$
						1905	30	$.305 \times 10^7$
AV-18 AV-19	28VDC	1	Vertical	1935	10			$.232 \times 10^7$
						700	20	$.185 \times 10^7$
		2		1760	4			$.417 \times 10^7$
		3		2170	25			$.044 \times 10^7$
AV-29 AV-32	115 VAC	1	*					
		2	Horizontal	790	20			1.079×10^7
						40	21	1.283×10^7

* There were no shorts providing measurable current greater in length than 30 sec.

TABLE B-III Sustained Hit Data for 15mm Fibers (con't)

Code: 1. Return Adjacent Terminal 2. Return Across Barrier 3. Main Power Output

RUN NUMBERS	VOLTAGE	CODE	ORIENTATION	MAX TIME SHORT		MAX CURRENT SHORT		EXPOSURE @ START
				TIME(sec)	I(ma)	TIME(sec)	I(ma)	[f-sec/m^3]
				1030	42			$.893 \times 10^7$
						140	100	1.283×10^7
AV-30 AV-31	115VAC	1	Vertical	335	4			1.44×10^7
						30	9	$.616 \times 10^7$
		2	*					
		3		1105	40			$.262 \times 10^7$
						80	40	$.387 \times 10^7$

* There were no shorts providing measurable current greater in length than 30 sec.

APPENDIX C

ATC-600 TEST SET SPECIFICATIONS

1. The ATC-600 is a test set intended to be used on aircraft parking ramps and designed to meet exacting functional test requirements of aircraft Transponder and DME systems. Housed in a rugged, compact case, it contains built-in signal generators and modulators for XPDR and selected DME frequencies. Its RF output is coupled to airborne equipment by a remote, tripod mounted antenna. Functional bench testing is accomplished using a 34dB pad between the ATC-600 and the XPDR or DME under test.

2. Transponder interrogation is selected between Mode A/C or Mode B. Mode A/C is further switched to display Pilot's code or Altitude code. Both code pulses and numerical readout are simultaneously displayed in all modes.

3. A meter indicates peak RF power and transmitter frequency of XPDR and DME units under test. Another meter indicates XPDR percent reply and DME interrogation PRF.

4. Two controls allow precise checking of the XPDR input pulse decoder gate and the spacing of the XPDR reply pulses by measuring F1 and F2 spacing. A front panel connector allows display of altitude from an encoding altimeter without using a transponder.

APPENDIX D

ASR-3 Operation Specifications

The following list of specifications is extracted from the Bendix Radio Inc. radar instruction manual.

1. RADAR SYSTEM COVERAGE.

This system is capable of detecting all aircraft of the light plane class, such as a Piper Cub, from five degrees to 20 degrees above the horizontal up to an altitude of 10,000 and a range of 26 miles through 360 degrees in azimuth.

2. ANTENNA PATTERN AND RATE OF SCANNING.

The azimuth beam width is 2.5 degrees at the 50 per cent power points, 4.5 degrees at the 10 per cent power points, and 6.25 degrees at the two per cent power points. The vertical radiation provides a cosecant-squared type coverage so as to meet the coverage specified in paragraph 3 of this summary. The antenna scanning is in a clockwise direction through 360 degrees in azimuth at a speed of 25 rpm. Speed variations are as follows:

± rpm for wind velocities up to 51.5 knots.
± rpm for wind velocities between 51.5 and 64 knots.

3. TYPE OF INDICATOR AND RANGE SCALES.

The console employs a 10-inch cathode-ray tube and provides a plan-position indicator (PPI) type display. Sweep ranges of 6, 10, 20, 30, and 50 nautical miles are provided and can be selected by a range selector switch. The sweep is intensity-modulated to provide two-mile markers on the 6- and 10-mile range, five-mile markers on the 20- and 30-mile ranges, and 10-mile markers on the 50-mile range. Decentering is also provided so that the origin of the sweep can be placed anywhere on the face of the PPI, thus, providing a sector scan having a maximum range of twice the sweep range in use up to a maximum range of 50 miles.

4. PRESENTATION OF DATA.

Normal, MTI, and map video are available at the console, each having a separate gain control. The normal and MTI video can be gated such that MTI video appears from zero to a selected range with normal video appearing beyond. The MTI range gating is variable from near zero to the maximum range of 50 nautical miles. Also, a provision is made whereby a controlled amount of normal video can be inserted into the MTI video in order to provide a background of normal video on the MTI display.

*Table XI input is taken from the Bendix Radio radar instruction book.

5. FREQUENCY RANGE.

2700 - 2900 megacycles.

6. TYPE OF FREQUENCY CONTROL.

Automatic frequency control of the local oscillator in the receiver circuits is provided to maintain a constant 30-megacycle i-f frequency.

7. MODULATION AND MODULATION CAPABILITIES.

Pulse type (radar).

8. POWER OUTPUT.

Peak power: 460 kilowatts
Average power: 550 watts

9. PULSE WIDTH AND REPETITION FREQUENCY.

Pulse width: 1 microsecond
Pulse repetition frequency: 1200 pps
Duty cycle: 0.0012

10. TYPE OF RECEIVER.

Superheterodyne

11. INTERMEDIATE FREQUENCY.

30 megacycles

12. REMOTE LINE CHARACTERISTICS.

Transmitter house video output:	7 to 10 volts video 70 volts pretrigger
Line compensator output:	1.5 volts video 25 volts pretrigger (minimum)

13. RECEIVER CHARACTERISTICS.

a. BANDWIDTH - The i-f bandwidth of the normal receiver is between 1.75 and 2.25 megacycles. The i-f bandwidth of the MTI receiver is approximately equal to the normal bandwidth. The bandwidth of the video circuits from the second detector to the indicator tube is at least 90 per cent of the i-f bandwidth.

b. NOISE FIGURE - The over-all noise figure relative to the minimum theoretical noise is 12 db or less.

c. SENSITIVITY - The sensitivity of the normal receiver is 90 db below a milliwatt when the signal to noise ratio (S/N)=2. The sensitivity of the MTI receiver equals that of the normal receiver.

d. OVER-ALL GAIN - The over-all gain including the i-f and video stages is 106 db.

14. FREQUENCY STABILITY DATA.

The magnetron warm-up drift is 3.5 megacycles maximum.

15. CHARACTERISTICS OF POWER SUPPLY REQUIRED FOR OPERATION.

a. 208 volts ac, 60 cycles, three phase at 9 kw at 0.84 power factor.

b. 120 volts ac, 60 cycles, one phase at 1.7 kw at 0.9 power factor.

c. Current and Power Factor at Various Loads:

(1) Transmitter Site - 208 volts ac, three phase

Condition	Operating Current	Power Factor	Power (watts)
One channel preheat; antenna off	7.3A/Ø	.85	2240
One channel preheat; one channel on; antenna on	25.3A/Ø	.81	7072
Both channels on; antenna on	33.8A/Ø	.84	8632

(2) Console Site - 120 volts ac, single phase

Condition	Starting Current	Operating Current	Power Factor	Power (Watts)
Console on; console equipment on		11 amp	.82	1200
Console on; console equipment on; video mapping on		17 amp	.90	1700

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